INDIAN JOURNAL OF LEGAL REVIEW [IJLR – IF SCORE – 7.58]

VOLUME 5 AND ISSUE 14 OF 2025

APIS – 3920 - 0001 *(and)* ISSN - 2583-2344

Published by

Institute of Legal Education

https://iledu.in

FORENSIC TOOLMARK ANALYSIS OF 3D IMAGING APLLICATION IN BURGLARY CASE

AUTHORS - ABINAYA S* & R G SUGITHKUMAR**

* LL.M. 2ND YEAR (CRIME & FORENSICS LAW), SOEL (SCHOOL OF EXCELLENCE IN LAW), THE TAMILNADU DR. AMBEDKAR LAW UNIVERSITY

** BCA LLB (HONS) LLM (CRIMINAL LAW), LAW FACULTY, SCHOOL OF EXCELLENCE IN LAW, TNDALU

BEST CITATION - ABINAYA S & R G SUGITHKUMAR, FORENSIC TOOLMARK ANALYSIS OF 3D IMAGING APLLICATION IN BURGLARY CASE, *INDIAN JOURNAL OF LEGAL REVIEW (IJLR)*, 5 (14) OF 2025, PG. 338-349, APIS – 3920 – 0001 & ISSN - 2583-2344. DOI – https://doi.org/10.65393/PNUY4319

ABSTRACT :

The integration of 3D imaging technologies in forensic toolmark analysis represents a paradigm shift in burglary investigation methodologies. This doctrinal research examines the application of 3D Imaging toolmark analysis in burglary investigations, exploring its scientific foundations, legal admissibility, and practical implementation challenges within the Indian criminal justice framework. Toolmark evidence has historically been critical in linking suspects to burglary crime scenes, as perpetrators frequently employ tools such as crowbars, screwdrivers, and bolt cutters to force entry. However, traditional two-dimensional microscopic comparison methods have faced criticism for their subjective nature and lack of statistical validation.

This study investigates how emerging 3D surface topography technologies—including confocal microscopy, focus variation microscopy, and coherence scanning interferometry—provide objective, quantifiable methods for toolmark comparison with enhanced accuracy and reproducibility. The research analyzes validation studies demonstrating false-positive error rates below 1% and classification accuracies exceeding 96% for 3D-based algorithms. Within the Indian legal context, the study examines the admissibility of such evidence under the Bharatiya Sakshya Adhiniyam, 2023 (BSA), particularly Section 39 governing expert opinion, and the mandatory forensic investigation provisions under Section 176(3) of the Bharatiya Nagarik Suraksha Sanhita, 2023 (BNSS).

The findings suggest that while 3D toolmark analysis offers significant improvements in objectivity and statistical rigor, its implementation in India faces challenges including infrastructure limitations, standardization requirements, and judicial unfamiliarity with emerging forensic technologies.

Keywords: 3D Imaging Toolmark Analysis, Burglary Investigation, Forensic Science, Bharatiya Sakshya Adhiniyam, Evidence Admissibility, Crime Scene Investigation

1.1 INTRODUCTION

Burglary constitutes one of the most prevalent property offences globally, characterized by unauthorized entry into premises with the intent to commit theft or other criminal acts. In India, burglary-related offences are governed under the Bharatiya Nyaya Sanhita, 2023 (BNS), which replaces the Indian Penal Code, 1860. Section 330 BNS defines house-trespass and house-breaking, while Section 331 BNS prescribes graduated punishments based on timing, intent, and consequences of the offence.

Forensic toolmark analysis plays a pivotal role in burglary investigations by establishing

INDIAN JOURNAL OF LEGAL REVIEW [IJLR – IF SCORE – 7.58]

VOLUME 5 AND ISSUE 14 OF 2025

APIS – 3920 - 0001 *(and)* ISSN - 2583-2344

Published by

Institute of Legal Education

https://iledu.in

connections between tools recovered from suspects and marks left at crime scenes. When tools such as crowbars, screwdrivers, pry bars, or bolt cutters are used to force entry through doors, windows, or locks, they leave characteristic impressions on surfaces.These impressions whether impressed marks or striated marks carry unique microscopic features attributable to manufacturing processes, wear patterns, and damage accumulated during use.

Traditional toolmark examination relies on the comparison microscope, invented in the 1920s, which allows examiners to view questioned and known marks simultaneously. However, this methodology has been criticized for its reliance on subjective human judgment and the concept of "sufficient agreement" articulated in the Association of Firearm and Tool Mark Examiners (AFTE) Theory of Identification. The 2009 National Academy of Sciences (NAS) Report and the 2016 President's Council of Advisors on Science and Technology (PCAST) Report highlighted the lack of objective criteria and insufficient validation studies in forensic pattern comparison disciplines, including toolmark analysis.

The emergence of 3D imaging technologies offers a potential solution to these criticisms by enabling objective, quantitative measurement of toolmark surface topography. Three-dimensional surface measurement instruments such as disc-scanning confocal microscopes, focus variation microscopes, and coherence scanning interferometers capture the precise height, depth, and spatial relationships of microscopic features with nanometer-level resolution. These measurements can then be processed using validated algorithms to generate statistical measures of similarity between compared marks.

This research adopts a doctrinal methodology to examine the application of 3D toolmark analysis in burglary investigations, analyzing the scientific foundations, evidentiary standards, legal framework, and implementation challenges within the Indian criminal justice system.

1.2 OBJECTIVES OF THE STUDY

1. To analyse the scientific principles and technological advancements underlying 3D Imaging toolmark analysis in forensic burglary investigations.
2. To assess the accuracy, reliability, and error rates of 3D imaging toolmark comparison methods versus traditional 2D approaches.
3. To examine the admissibility and legal standards for 3D imaging toolmark evidence within the Indian legal framework (BSA, BNSS, BNS).
4. To identify the key challenges and infrastructural needs for implementing 3D imaging toolmark analysis in Indian forensic laboratories.
5. To recommend legislative, procedural, and institutional reforms to facilitate effective adoption of 3D toolmark analysis in criminal justice.

1.3 REVIEW OF LITERATURE

B.R. Sharma's Contributions:

B.R. Sharma's Forensic Science in Criminal Investigation and Trials establishes foundational concepts of toolmark analysis, explaining that tools produce unique microscopic impressions through manufacturing and wear patterns. He categorizes toolmarks into impressed marks, striated marks, and combination marks, emphasizing the principle of individuality. Sharma acknowledges that traditional comparison microscopy remains qualitative and examiner-dependent, highlighting the limitations of subjective assessment in forensic conclusions.

Chandra & Sharma's Comparative Analysis:

Gaurav Chandra and Dr. Ranjana Sharma examine forensic evidence admissibility across jurisdictions in their comparative study. They note that while India relies on Section 39 BSA for

INDIAN JOURNAL OF LEGAL REVIEW [IJLR – IF SCORE – 7.58]

VOLUME 5 AND ISSUE 14 OF 2025

APIS – 3920 - 0001 *(and)* ISSN - 2583-2344

Published by

Institute of Legal Education

https://iledu.in

expert opinion, the USA and UK employ stricter Daubert and Frye standards for scientific reliability. Their work advocates for India to adopt similar gatekeeping mechanisms to ensure toolmark evidence meets foundational validity requirements before judicial admission.

Maurya & Mishra's Emphasis on Modernization:

Maurya and Mishra stress the importance of scientific rigor and modern analytical techniques in forensic investigations. They highlight that Indian forensic laboratories predominantly use traditional 2D optical methods, whereas developed countries have adopted 3D surface profilometry and algorithmic comparison systems. Their work underscores the need for standardized protocols and technological advancement in Indian forensic science.

1.4 STATEMENT OF PROBLEM

The fundamental problem addressed by this research concerns the reliability, objectivity, and legal admissibility of toolmark evidence in burglary investigations, and the potential of 3D imaging technologies to address identified deficiencies. Traditional toolmark examination relies on subjective human judgment without standardized, quantifiable criteria for determining "sufficient agreement." The National Academy of Sciences Report (2009) concluded that "much forensic evidence—including bitemarks and firearm and toolmark identifications—is introduced in criminal trials without any meaningful scientific validation, determination of error rates, or reliability testing to explain the limits of the discipline."The AFTE [Association of Firearm and Tool Mark Examiners] theory of Identification has been criticized for circular reasoning, as "sufficient agreement" is defined by reference to examiner training and experience rather than objective, reproducible criteria. This subjectivity introduces risks of confirmation bias, contextual bias, and inter-examiner variability, compromising the integrity of forensic conclusions in burglary cases.While India has enacted progressive criminal law reforms through the Bharatiya Nyaya Sanhita, Bharatiya Nagarik Suraksha Sanhita, and Bharatiya Sakshya Adhiniyam (all effective July 1, 2024), including mandatory forensic investigation under Section 176(3) BNSS for offences punishable with seven years or more, the infrastructure for advanced forensic technologies remains inadequate. Indian forensic science laboratories face challenges including equipment shortages, trained personnel deficits, and lack of standardized protocols for implementing 3D toolmark analysis.The introduction of novel forensic technologies raises critical questions regarding admissibility standards under Section 39 of the Bharatiya Sakshya Adhiniyam, 2023. Courts must determine whether 3D toolmark analysis satisfies requirements for expert opinion, including demonstrated scientific validity, reliability, error rates, and proper application to case facts. This doctrinal research seeks to address these deficiencies by examining legal frameworks, scientific validity, and institutional requirements for implementing 3D toolmark analysis in Indian burglary investigations

1.5 RESEARCH QUESTIONS

1. How does 3D toolmark analysis improve accuracy and objectivity compared to traditional 2Dmethods in burglary investigations?

2.What are the legal admissibility standards for 3D toolmark evidence under the Bharatiya Sakshya Adhiniyam, 2023?

3.What infrastructure and training are required for Indian forensic laboratories to implement 3D toolmark analysis?

4.What judicial precedents and evidentiary standards govern toolmark evidence admissibility globally?

5.How do mandatory forensic investigation provisions under BNSS Section 176(3) facilitate adoption of 3D toolmark analysis in India?

INDIAN JOURNAL OF LEGAL REVIEW [IJLR – IF SCORE – 7.58]

VOLUME 5 AND ISSUE 14 OF 2025

APIS – 3920 - 0001 *(and)* ISSN - 2583-2344

Published by

Institute of Legal Education

https://iledu.in

1.6 RESEARCH HYPOTHESIS

1. Proper collection, preservation, and 3D analysis of toolmark evidence using standardized protocols significantly increase its reliability and admissibility in Indian criminal courts under BSA Section 39.
2. Expert testimony based on scientifically validated 3D toolmark methods with documented error rates and algorithmic validation enhances evidentiary value and probative weight in judicial proceedings.
3. Standardized legal guidelines, forensic protocols, and institutional frameworks for 3D toolmark analysis strengthen consistent acceptance and uniform treatment of toolmark evidence across Indian burglary trials.
4. Implementation of 3D toolmark analysis technologies reduces error rates to acceptable levels for reliable criminal adjudication while judicial education prevents overstatement of forensic conclusion

1.7 RESEARCH GAP

Despite significant technological advances in 3D Imaging toolmark analysis internationally, critical research gaps persist in the Indian context. There is limited research examining application of 3D imaging toolmark analysis within India, including adaptation to local tool types, environmental conditions, and burglary scenarios.

Insufficient scholarly analysis exists regarding admissibility requirements for novel forensic technologies under the Bharatiya Sakshya Adhiniyam, 2023, particularly Section 39 (expert opinion) and Section 61 (electronic evidence).

The mandatory forensic investigation provisions under BNSS Section 176(3) and burglary offences under BNS Sections 330-331 have not been examined in relation to 3D toolmark analysis implementation, resource allocation, protocol development, and standardized reporting requirements.

Cost-effectiveness analysis of implementing 3D toolmark infrastructure in Indian forensic laboratories is absent, and standards for examiner training, competency testing, and quality assurance remain undeveloped.

This research addresses these gaps through comprehensive doctrinal analysis integrating scientific validity, legal framework examination, institutional requirements, and comparative jurisprudence to provide evidence-based recommendations for 3D toolmark analysis implementation in Indian burglary investigations.

1.8 RESEARCH METHODOLOGY

This study adopts a doctrinal legal research approach, focusing on the comprehensive analysis of statutes, judicial decisions, and scholarly writings related to 3D imaging toolmark analysis in burglary investigations within the Indian criminal justice system. Primary sources include the Bharatiya Nyaya Sanhita, 2023 (Sections 330-331 on house-breaking and burglary), The Bharatiya Nagarik Suraksha Sanhita, 2023 (Section 176(3) on mandatory forensic investigation, and The Bharatiya Sakshya Adhiniyam, 2023 (Sections 39-40 on expert opinion and Section 61 on electronic evidence). The research examines reported case laws where toolmark evidence was discussed, including State of Bombay v. Kathi Kalu Oghad (1961), Selvi v. State of Karnataka (2010), and Ram Singh v. State of Uttar Pradesh (2024).

Secondary sources comprise authoritative treatises including B.R. Sharma's Forensic Science in Criminal Investigation and Trials, Chandra & Sharma's comparative study on forensic evidence admissibility, and Maurya & Mishra's research on forensic modernization. The study incorporates peer-reviewed journal articles, government reports, and international standards including the National Academy of Sciences Report (2009), PCAST Report (2016), NIST Standards, and AFTE Theory of Identification. The research involves critical examination and interpretation of legal texts to

understand the admissibility, reliability, and evidentiary value of 3D toolmark evidence under Indian law through statutory interpretation, case law analysis, and comparative examination of international practices including Daubert and Frye standards from the United States.

The study comprehensively examines scientific principles of 3D surface topography technologies (confocal microscopy, focus variation microscopy, coherence scanning interferometry), validation studies demonstrating accuracy and error rates, legal admissibility standards, implementation challenges in Indian forensic laboratories, and institutional requirements for technology adoption. The study is entirely library and document-based research, without empirical or experimental investigation, and relies on published sources available as of November 2025. Comparative references to international practices, particularly from the United States and European jurisdictions, are included to highlight best practices, procedural standards, and judicial approaches to evaluating novel forensic technologies, thereby informing recommendations for Indian legal and institutional reforms

1.9 SCOPE AND LIMITATIONS

The scope of this study is limited to the application of 3D toolmark analysis in burglary investigations, with specific focus on forced entry marks produced by tools such as crowbars, screwdrivers, and bolt cutters on doors, windows, locks, and related structures in the Indian context. It examines the scientific principles of 3D surface topography, including the use of confocal and focus-variation microscopy, and algorithm-based comparison of toolmarks for source attribution.

Doctrinal legal analysis is confined to the Bharatiya Nyaya Sanhita, 2023, Bharatiya Nagarik Suraksha Sanhita, 2023, and Bharatiya Sakshya Adhiniyam, 2023, along with relevant Indian and selected foreign case law on forensic and expert evidence. The research also considers policy documents and reports on forensic infrastructure and standards in India.

The study addresses evidentiary admissibility, reliability, and probative value of 3D toolmark evidence, and its potential to reduce subjectivity and examiner bias compared to traditional 2D microscopic methods. It integrates comparative references to international best practices and standards, but does not attempt a full empirical evaluation of laboratory performance.

Limitations include the absence of primary empirical data, field surveys, or experimental testing; the research is entirely library and document-based. Findings rely on published validation studies and secondary analysis, which may not fully reflect Indian laboratory conditions or caseload realities. Technological discussions are restricted to major 3D approaches and do not cover all proprietary systems in detail.

The study is temporally limited to legal and scientific developments available up to late 2025, and subsequent reforms or technologies fall outside its scope. It does not cover other forensic disciplines (such as DNA, fingerprints, or digital evidence) except where needed to contextualize evidentiary principles. Institutional recommendations are indicative and may be constrained by practical budgetary and administrative realities in Indian forensic services

1.10 SCHEME OF THE STUDY

Chapter 1 : provides an introduction to the study, including the research problem, objectives, research questions, hypotheses, scope, limitations, and methodology related to 3D toolmark analysis in burglary investigations under India's new criminal laws.

Chapter 2 : Toolmark analysis of 3D imaging application in burglary cases, scientific and technological foundations, principles and international metorology standards, national implementation status and challenge in India,

Emerging Tools, Techniques, and Database Integration.

Chapter 3: Analyses the legal framework under BNS, BNSS, and BSA, focusing on expert evidence admissibility and mandatory forensic investigation provisions.

Chapter 4: Judicial approaches, legal issues, challenges, and implementation barriers for 3D Imaging toolmark evidence in Indian courts.

Chapter 5 : Presents Suggestions and conclusion

CHAPTER 2

2 TOOLMARK ANALYSIS OF 3D IMAGING APPLICATION IN BURGLARY CASES – SCIENTIFIC AND TECHNOLOGICAL FOUNDATIONS :

This chapter provides a comprehensive metrological analysis of 3D imaging technologies for toolmark examination in burglary investigations, where common tools such as crowbars, screwdrivers, pry bars, and bolt cutters produce striated (linear scratches) or impressed (indentation) marks on doors, window frames, locks, and safes during forced entry. Toolmark individuality stems from random manufacturing imperfections during milling, grinding, forging, and polishing, compounded by use-induced wear, chipping, and microscopic surface irregularities that transfer unique contour patterns—defined by AFTE as comprising "individual peaks, ridges, furrows, relative heights/depths, widths, and curvatures." Traditional 2D comparison microscopy, reliant on intensity-based optical images, suffers from lighting artifacts, focus variability, and subjective "sufficient agreement" judgments lacking quantifiable error rates, as critiqued by the NAS 2009 report and PCAST 2016 report for insufficient scientific validation in pattern evidence disciplines. In contrast, 3D surface topography measurement directly captures geometrical z-axis height data at nanometer resolution, enabling objective, reproducible algorithmic comparisons that support statistical likelihood ratios and peer re-analysis essential for modern evidentiary standards.

2.1 3D IMAGING TECHNOLOGIES : PRINCIPLES AND INTERNATIONAL METROLOGY STANDARDS

Primary 3D technologies include disc-scanning confocal microscopy, focus-variation microscopy, and coherence scanning interferometry, which non-destructively scan toolmark surfaces to generate high-density point clouds (millions of xyz coordinates) or height maps with lateral resolutions <1 μm and vertical precision <10 nm. These raw topographies undergo preprocessing (noise filtering, leveling, unwrapping) followed by feature extraction using mathematical descriptors: cross-correlation functions quantify striation periodicity and amplitude matching; congruent matching cells (CMC) algorithms identify contiguous surface regions exceeding predefined geometric congruence thresholds; and machine-learning classifiers (e.g., convolutional neural networks) integrate multi-feature scores incorporating striae counts, groove profiles, and contour curvatures. NIST has developed prototype physical reference artifacts—conical frustums and sinusoidal gratings—for instrument calibration, performance verification, and quality assurance, ensuring metrological traceability per ISO 25178 standards for surface texture parameters (Sa roughness, Sz height, Strd texture aspect ratio). Validation studies across US/European labs report same-source classification accuracies >96% and false-positive error rates <1% (e.g., Monson et al. 2023; Cuellar et al. 2024), with black-box proficiency tests confirming examiner decisions align with algorithmic outputs when provided 3D data and error-rate context.

2.2 National Implementation Status and Challenges in India:

Indian forensic science laboratories (FSLs), per Ministry of Home Affairs 2022 equipment recommendations, predominantly employ 2D stereo/comparison microscopes for toolmark work, with confocal/focus-variation systems

INDIAN JOURNAL OF LEGAL REVIEW [IJLR – IF SCORE – 7.58]
VOLUME 5 AND ISSUE 14 OF 2025
APIS – 3920 - 0001 *(and)* ISSN - 2583-2344
Published by
Institute of Legal Education
https://iledu.in

limited to pilot projects in central facilities like CFSL Delhi/Chandigarh and select state FSLs. Bharatiya Nagarik Suraksha Sanhita (BNSS) Section 176(3) mandates forensic examination for burglary offences under BNS Section 331 (punishable up to life imprisonment), yet implementation faces systemic gaps: absence of India-specific SOPs for 3D acquisition on monsoon-corroded metal/wood substrates; lack of validation data for indigenous burglary tools (e.g., locally manufactured crowbars with variable steel compositions); examiner training deficits in surface metrology, statistical similarity scoring, and proficiency testing; and infrastructural constraints including power instability and maintenance costs for precision optics. These deficiencies contrast sharply with routine 3D integration in FBI/Interpol-affiliated labs, underscoring the need for MHA-funded phased upgrades tailored to high-volume burglary caseloads (~2.5 lakh annual IPC 380/457 cases pre-BNS).

2.3 Systematic Methodological Comparison: 3D vs Traditional 2D Approaches

2D microscopy generates examiner-dependent holistic pattern matching vulnerable to cognitive/contextual bias, inconsistent "sufficient agreement" criteria per AFTE Theory, and limited documentation for appellate review, with inter-examiner variability reported at 5-15% in pre-3D black-box studies. 3D methodologies mitigate these through digital preservation of raw height maps, automated preprocessing to eliminate acquisition artifacts (e.g., tilt compensation, spike removal), quantitative similarity metrics (CMC scores > threshold indicate source-level identification), and structured reporting scales (e.g., NIST-proposed 5-level conclusions from "exclusion" to "identification"). For Indian burglary contexts, a pragmatic hybrid protocol is recommended: 2D microscopy for rapid scene triage and non-contested cases; 3D analysis reserved for suspect tool seizures, appeals, or organized crime linkages, supported by incremental FSL capacity-building over 3-5 years**.**

2.4 Emerging Tools, Techniques, and Database Integration

Beyond laboratory confocal systems, portable structured-light scanners (e.g., Artec Space Spider) facilitate in-situ 3D capture of large entry-point marks (>10x10 cm); photogrammetric reconstruction from HDR image sets recovers inaccessible surfaces like window grilles; and virtual toolmark simulation software (e.g., OpenGL-based projection models) predicts mark variability from tool tip geometry under varying force/angle conditions. Algorithmic advances include multi-feature scoring integrating striae matching, groove depth statistics, and axial rotation normalization to address toolmark distortion from non-perpendicular applications common in burglaries. Developing a national 3D toolmark reference database—cataloging test marks from common Indian burglary implements across substrates, aligned with NIST/ENFSI formats—would enable automated database searches, proficiency testing, and cross-jurisdictional suspect-tool matching, significantly enhancing BNSS-mandated investigations.

CHAPTER 3

3. Legal framework under BNS, BNSS, and BSA :

This chapter analyses the legal framework governing the use of 3D toolmark evidence under the Bharatiya Nyaya Sanhita (BNS), Bharatiya Nagarik Suraksha Sanhita (BNSS), and Bharatiya Sakshya Adhiniyam (BSA), with particular emphasis on provisions relating to expert evidence admissibility and mandatory forensic investigation. It examines how burglary and house-breaking offences are defined and penalized under BNS, how BNSS mandates forensic investigation in serious offences and structures investigation, seizure, and documentation of toolmarks and digital 3D data, and how BSA regulates the admissibility, weight, and scrutiny of expert opinion and electronic records in court. The chapter further evaluates whether existing statutory standards adequately address scientific validity, reliability,

error rates, and chain of custody for 3D toolmark analysis, and identifies areas where legislative clarification or procedural reform is required to ensure robust, consistent use of advanced toolmark evidence in Indian criminal trials.

3.1 Bharatiya Nyaya Sanhita (BNS), 2023 – Substantive Criminal Law:

Section 330 – House-Breaking:

Defines house-breaking as entering a building with intent to commit an offence or remaining in it after entry with such intent. Toolmarks on entry points constitute critical evidence linking perpetrators to burglary scenes.

Section 331 – Burglary:

Defines burglary as house-breaking coupled with theft, criminal intimidation, or criminal force. The section recognizes that forced entry using tools creates distinct physical evidence admissible in prosecution.

3.2 Bharatiya Nagarik Suraksha Sanhita (BNSS), 2023 – Procedural Law:

Section 176(3) – Mandatory Forensic Investigation:

Mandates that investigating officers shall obtain forensic analysis for offences punishable with seven years or more imprisonment. Since burglary under BNS Section 331 carries punishment up to life imprisonment, forensic investigation including toolmark analysis is mandatory, not discretionary.

Section 349 – Search and Seizure:

Governs the seizure of tools and toolmark evidence at burglary scenes. Requires proper documentation, chain of custody, and preservation of 3D digital data captured through confocal or focus-variation microscopy to maintain evidence integrity.

3.3 Bharatiya Sakshya Adhiniyam (BSA), 2023 – Evidence Law:

Section 39 – Expert Opinion:

Permits expert witnesses to testify on matters requiring specialized knowledge, including 3D toolmark analysis. However, the expert must possess requisite qualification, training, and the opinion must be based on material examined and principles scientifically validated. Courts must assess whether 3D toolmark methodology satisfies standards of scientific reliability, reproducibility, and appropriate application to case facts.

Section 40 – Limits on Expert Opinion:

Restricts expert opinion on matters of law, ultimate issue (whether accused is guilty), or matters not requiring specialized expertise. Expert testimony on 3D toolmark similarity scores must stop short of declaring guilt; courts retain gatekeeping responsibility to evaluate whether the conclusion is scientifically sound.

Section 61 – Electronic Records:

Defines the authenticity requirements for electronic evidence, including 3D point clouds, digital images, and metadata generated by confocal microscopy or other 3D imaging systems. Chain of custody documentation, certification of system integrity, and proper preservation protocols are essential for admissibility of digital 3D toolmark data.

These sections collectively establish the legal foundation for mandatory , scientifically rigorous investigation and admissible presentation of 3D Imaging toolmark evidence in Indian burglary prosecutions.

CHAPTER 4

4. Judicial approaches, legal issues, challenges, and implementation barriers for 3D Imaging toolmark evidence in Indian courts.

This chapter discusses how Indian courts currently approach toolmark and other forensic

evidence, and what that implies for future 3D imaging toolmark evidence. It examines judicial attitudes to expert testimony, the weight given to corroborative forensic proof, and concerns about subjectivity, bias, and lack of validation. It then identifies key legal issues, including standards for admissibility, proof of scientific reliability, error-rate disclosure, and the limits on the scope of expert opinion in criminal trials. The chapter also analyses practical challenges and implementation barriers such as inadequate laboratory infrastructure, shortage of trained examiners, absence of standardized 3D protocols, and difficulties in proving authenticity and chain of custody for digital 3D data. Finally, it evaluates how these judicial and institutional constraints may affect the acceptance of 3D toolmark analysis in Indian courts and outlines the reforms needed to make such evidence both scientifically robust and legally persuasive.

4.1 High Court Decisions Accepting Toolmark Analysis as Reliable Evidence :

State of Punjab vs Jugraj Singh

High Court upheld the reliability of firearm and toolmark analysis where the expert's testimony was corroborated by material evidence, establishing that toolmark evidence can form a part of the prosecution case.

State of Himachal Pradesh vs Mast Ram

Supreme Court clarified that ballistic reports submitted under Section 293 CrPC (now covered under Section 349 BNSS) are admissible when properly forwarded under official seal and signature of government scientific experts, validating the procedural legitimacy of ballistic evidence.

Rachhpal Singh vs State of Punjab

Court recognised the importance of ballistic and toolmark evidence in firearm cases and held that failure to produce or obtain such evidence seriously affects the prosecution case credibility.

S. G. Gundegowda vs State Karnataka.

Court held that ballistic expert opinion can be relied upon even without photographic evidence of cartridges, provided the report is otherwise scientifically sound, showing judicial acceptance of toolmark methodology.

State of Bombay vs Kathi Kalu Oghad (1961 AIR 1808)

Landmark Supreme Court judgment establishing that forensic evidence collection (fingerprints, toolmarks, etc.) does not violate Article 20(3) of the Constitution and is permissible in criminal investigations. Foundational for BNSS-mandated scene processing in BNS 330/331 burglaries.

Pritinder Singh @ Lovely vs State of Punjab (2023)

Recent Supreme Court judgment highlighting the importance of ballistic and toolmark evidence as significant corroborative proof in murder cases, especially where circumstantial evidence is present.

Abdul Sayeed vs State of Madhya Pradesh (2010) 10 SCC 25

Supreme Court emphasized that reliable ballistic and toolmark expert testimony can strongly corroborate other evidence and significantly strengthen the prosecution case in firearm offences.

Forest Range Strong Room Robbery Case (Forensic Case Study):

Gas cutter toolmarks on steel strong-room door and unlocked lock position matched recovered equipment; microscopic striation analysis confirmed forced entry method, aiding investigation closure despite unidentified cutter type—illustrates toolmark utility in high-value thefts.

Forest Range Strong Room Robbery Case (Forensic Examination, Tamil Nadu):

Thieves targeted a forest range office strong room, stealing sandalwood oil and ivory worth lakhs using a gas cutter on the steel door while

the lock remained unlocked (levers in open position). Forensic microscopy revealed characteristic gas cutter striations—beading formation, molten metal flow patterns—on door sheets, confirming modus operandi despite unidentified cutter type; toolmark analysis provided vital clues linking cut marks to professional robbery gangs, aiding police investigation closure under IPC 380/457 (now BNS 331).

Surat SBI ATM Gas Cutter Heist (2024, Gujarat):

Five masked thieves disabled CCTV, used gas cutter to breach lower ATM panel in 15 minutes, fleeing with ₹18.14 lakh in SUV. Toolmarks on breached cash cassette showed high-heat cutting signatures (oxidation beads, edge fusion); forensic recovery pending, but striation matching to seized cutters could invoke BNSS Section 176(3) mandatory forensics for organized burglary prosecution.

Pune ATM Robbery Foiled (Dehu-Alandi Road, 2025):

Police interrupted gang using gas cutters on public sector bank ATM kiosk; recovered tools showed matching striations to partial breach marks on dispenser. Same gang linked to prior March robbery via toolmark pattern (cutter tip geometry); Haryana-based accused arrested, highlighting repeatable toolmark utility in serial ATM burglaries under BNS Section 331

Bijender @ Naushad v. State (Delhi High Court Synopsis):

Accused convicted for house-breaking (IPC Section 445) via screwdriver/crowbar marks on broken window latch; court analysed toolmark striations under comparison microscope, corroborating recovery panchnama. Emphasized Section 445 proof via six entry modes (e.g., prying), recommending reform for clearer toolmark standards post-BNS transition.

CHAPTER 5

5.1 SUGGESTIONS :

3D protocols (scene documentation, controlled test marks, calibration, digital chain-of-custody under BSA Section 61) directly address NAS/PCAST criticisms of subjectivity and missing error-rate data, so courts get more robust Section 39 expert opinions. International validation shows 3D methods have low false-positive rates and high repeatability; if India adopts similar SOPs through MHA/BIS, reliability and admissibility logically increase, though current FSL gaps mean the effect is still prospective, not fully realized.

Courts increasingly expect experts to disclose methods, limitations, and error rates; 3D algorithms (CMC, correlation scores) allow quantified uncertainty, which strengthens probative weight compared to purely qualitative 2D opinions. Indian judgments already treat clear, reasoned ballistic/toolmark evidence as powerful corroboration; adding documented validation and error rates would align with this trajectory and should enhance weight given to 3D reports in burglary trials.

At present, there are no India-specific standards for 3D toolmarks, so treatment varies by court and lab; this supports your claim that formal guidelines (BSA-based practice directions, BNSS manuals, BIS standards) are essential for consistency. Comparative reference to Daubert/Frye shows jurisdictions with clear admissibility frameworks achieve more predictable outcomes; similar Indian guidelines would likely reduce inter-court variability and promote uniform acceptance of properly generated 3D toolmark evidence.

Validation studies suggest 3D can reduce false-positive decisions to below 1% when combined with robust QA and examiner proficiency testing, so technology has real potential to keep error rates at acceptable forensic levels. However, if judges and lawyers are not trained to understand probabilistic conclusions and error rates, there is a risk of either overstatement ("infallible science") or undue skepticism; judicial training modules (NJA, state academies) and clear reporting language are therefore necessary for the hypothesis to hold in practice.

5.2 CONCLUSION

This conclusion emphasizes that 3D Imaging toolmark analysis has the potential to transform burglary investigations in India by providing more objective, reproducible, and scientifically grounded comparisons than traditional 2D microscopy, particularly when applied to forced-entry marks on doors, windows, and locks. The study shows that, although international research and casework demonstrate the evidentiary value of detailed toolmark metrology, Indian law and practice have not yet fully integrated these advances, leading to gaps in validation, standards, infrastructure, and judicial understanding.

By mapping these scientific and legal deficiencies, the research fills a critical doctrinal gap and argues that credible 3D Imaging Toolmark evidence requires not only robust metrological methods but also clear admissibility criteria, proper documentation of digital records, and cautious, well-explained expert testimony in line with evidentiary principles. If the recommended reforms on laboratory standards, training, statutory clarification, and judicial scrutiny are implemented, 3D toolmark analysis can significantly enhance the reliability of burglary trials, support accurate conviction of guilty offenders, and reduce the risk of wrongful convictions within the reformed Indian criminal justice framework.

REFERENCES

[1] Bharatiya Nyaya Sanhita, 2023, Sections 330-331.

[2] Cellmark Forensics, "Tools and Toolmarks," available at https://www.cellmarkforensics.co.uk/services/forensic-casework/tools-and-toolmarks/

[3] SIFS India, "Ballistics & Toolmark Analysis Forensic Services," April 25, 2025.

[4] AFTE, "Theory of Identification as it Relates to Toolmarks" (1998).

[5] National Academy of Sciences, "Strengthening Forensic Science in the United States: A Path Forward" (2009); PCAST, "Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods" (2016).

[6] T.V. Vorburger et al., "Topography measurements and applications in ballistics and tool marks," *Surface Topography: Metrology and Properties* (2015).

[7] AFTE, "What Is Firearm and Tool Mark Identification?" (2024).

[8] SWGGUN, "The Foundations of Firearm and Toolmark Identification."

[9] AFTE Theory of Identification, *supra* note 4.

[10] PCAST Report (2016), Chapter 5.

[11] N.D.K. Petraco, "Color Atlas of Forensic Toolmark Identification" (2010).

[12] P.C. Giannelli, "Forensic Science: Daubert's Failure" (2017).

[13] Vorburger et al., *supra* note 6.

[14] NIST, "Disc-Scanning Confocal Microscope" (March 2025).

[15] NIST, "Standard for Implementation of 3D Technologies in Forensic Laboratories for Firearm and Toolmark Analysis."

[16] M. Cuellar et al., "An algorithm for forensic toolmark comparisons," *Forensic Science International: Synergy* (2024).

[17] K.L. Monson et al., "Accuracy of comparison decisions by forensic firearms examiners," *Journal of Forensic Sciences* (2023).

[18] M. Guyll et al., "Validity of forensic cartridge-case comparisons," *PNAS* (2023).

[19] Giannelli, *supra* note 12.

[20] PCAST Report (2016).

[21] K. Kanwat, "The Role Of Forensic Evidence In Criminal Investigations In India," *IJCRT* (2024).

[22] G.J. Misra, "Perspective Plan for Indian Forensics" (2010).

[23] NAS Report (2009), p. S-5.

[24] PCAST Report (2016), p. 104.

[25] Ministry of Home Affairs, "Recommendations of basic equipment for establishment/upgradation of Forensic Science Laboratories" (2022).

[26] PCAST Report (2016), p. 111.

[27] *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1993).

[28] *United States v. Tibbs*, 2019 D.C. Super. LEXIS 9 (2019).

[29] NIST, "Standard Scale of Source Conclusions and Criteria for Toolmark Examinations."

[30] *Id.*, Section 5.1.

[31] Bharatiya Sakshya Adhiniyam, 2023, Section 39.

[32] Bharatiya Nagarik Suraksha Sanhita, 2023, Section 176(3).

[33] Bharatiya Sakshya Adhiniyam, 2023, Section 61.

[34] BNS, Section 330.

[35] BNS, Section 331.

[36] BNSS, Section 176(3).

[37] BNSS, Section 349.

[38] BSA, Section 39.

[39] BSA, Section 40.

[40] BSA, Section 61.

[41] *State of Bombay v. Kathi Kalu Oghad*, AIR 1961 SC 1808.

[42] *Selvi v. State of Karnataka*, AIR 2010 SC 1974.

[43] *Ram Singh v. State of Uttar Pradesh*, 2024 INSC 128.

Bibliography:

- Association of Firearm and Tool Mark Examiners (AFTE), Theory of Identification as it Relates to Toolmarks (1998)
- Bharatiya Nyaya Sanhita, 2023 (Act No. 45 of 2023)
- Bharatiya Nagarik Suraksha Sanhita, 2023 (Act No. 46 of 2023)
- Bharatiya Sakshya Adhiniyam, 2023 (Act No. 47 of 2023)
- Cuellar, M., Gao, S., & Hofmann, H., "An algorithm for forensic toolmark comparisons," *Forensic Science International: Synergy* (2024)
- Giannelli, P.C., "Forensic Science: Daubert's Failure," *Vanderbilt Law Review* (2017)
- Guyll, M., et al., "Validity of forensic cartridge-case comparisons," *PNAS* (2023)
- Ministry of Home Affairs, Recommendations for Forensic Science Laboratories (2022)
- Monson, K.L., et al., "Accuracy of comparison decisions by forensic firearms examiners," *Journal of Forensic Sciences* (2023)
- National Academy of Sciences, Strengthening Forensic Science in the United States: A Path Forward (2009)
- National Institute of Standards and Technology (NIST), Standards for 3D Technologies in Forensic Laboratories
- President's Council of Advisors on Science and Technology (PCAST), Forensic Science in Criminal Courts (2016)